Two-micron Detector Development Using Sb-based Material Systems

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Outline

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- ❖ Sb-based detector applications
- ❖ Sb-based detector technology advantages
- ❖ Relevance to Earth Science and to Exploration Systems
- ❖ Detector Characterization at LaRC
- ❖ Conclusions

Overview

2-micron Detector Technology

- Sb-based detector
  - ❖ improves the measurement capability to achieve broad band sensitivity (wavelength range includes Si plus extended wavelength InGaAs detector)
  - ❖ enable new measurements with reduced complexity (e.g. electronics, optics, etc.), weight, size and cost of the system
- Detection of broadband with a single Sb-based detector
  - ❖ eliminates the requirements of Si plus extended wavelength InGaAs detectors in a system

Two-micron Detector Development

Objective

Develop, test, and implement new technology 2 μm detectors for applications to laser remote sensing from ground, aircraft, and space

Sb-based Detector Applications

- Detectors with responsivity at broad wavelengths are needed to span a wide wavelength range for the following applications
    - CO_2, O_3, H_2O, and CH_4
    - aerosols and clouds
    - detection of a large number of species in the visible-near infrared using active and passive remote sensing techniques, and
    - enable new science and lower-cost missions through lighter instruments

Sb-based Detector Technology Advantages

- Use a *single element Photodiode (PD)* that responds to CO_2 line and water vapor
- Spectral response in the 0.6 to 2.4 µm wavelength range with high gain and low noise
  - ❖ Existing photodiode doesn't provide same spectral coverage, and also not much gain and low noise
  - ❖ Simultaneous broad-spectral capability to fabricate detector that can respond in the 0.6 to 2.4 µm wavelength range with high gain and low noise

Two-micron Detector Development

Relevance to Earth Science and to Exploration

This custom-designed detector will boost new measurements with
reduced laser power and enhance the measurement capabilities for

- CO_2 profiling and water vapor profiling, aerosol and cloud profiling, and atmospheric pollutants monitoring that use wavelengths in the 0.6- to 2.4-µm range for earth atmospheric remote sensing
- Detecting column amounts of carbon dioxide (2.05 micron), water vapor (1.9-micron), and other trace gases in extreme environments of Mars that has direct relevant to NASA's exploration systems

Detector Characterization at LaRC

- Acquired existing InGaAs, InGaAsSb, and HgCdTe 2-μm detectors
- Acquired custom-designed InGaAsSb quaternary detectors fabricated using Liquid Phase Epitaxy (LPE) and Molecular Beam Epitaxy (MBE) techniques.
- Carried out spectral responsivity calibration at different bias voltages and temperatures
- Calculated gain and detectivity variation with bias voltage and temperature at 2.05-μm incident radiation

Existing and Custom-Designed Detectors

Manufacturer	Existing Devices	Custom-Designed Devices
Hamamatsu Corp	InGaAs (2.3 µm cutoff) (I)	
Hamamatsu Corp	InGaAs (2.6 µm cutoff) (II)	
Judson Technologies	HgCdTe (2.7 µm cutoff) (III)	
Astro-Power, Inc	InGaAsSb (2.1 µm cutoff)	
AstroPower, Inc (LPE) University of Delaware (MBE)		InGaAsSb (2.1 µm cutoff) InGaAsSb (2.5 µm cutoff)
Rensselaer Polytechnic Institute		InGaSb/GaSb (2.25 µm cutoff)
Rensselaer Polytechnic Institute		InGaSb/InGaSb (2.08 µm cutoff)

Detector Calibration

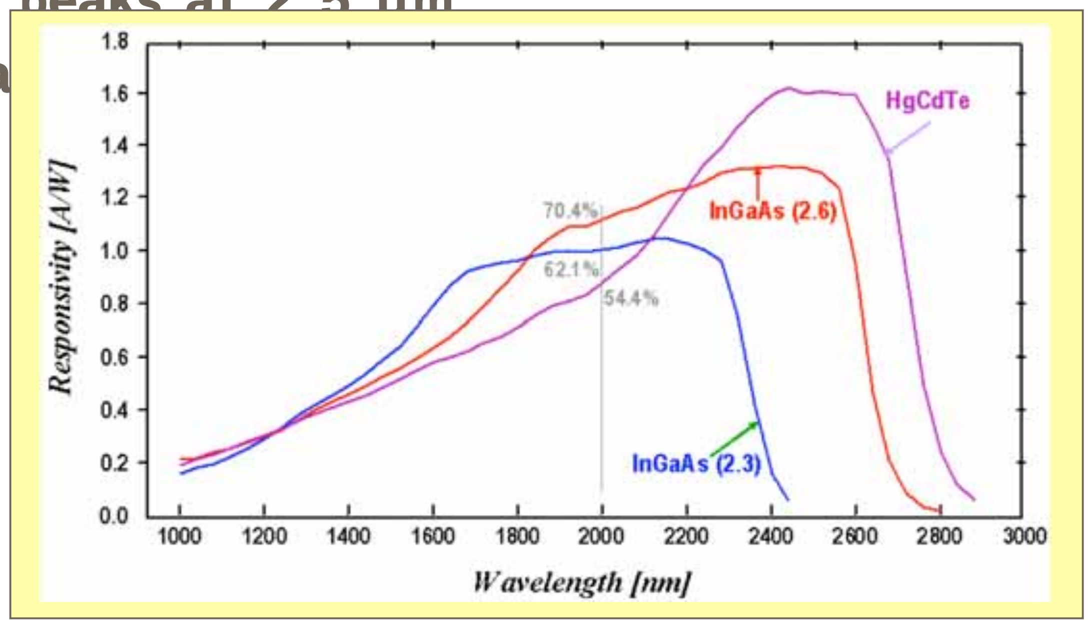
Setup

1- Monochromator
2- Detector Box
3- Detector Chamber with Water circulation and Nitrogen Purging
4- Current-to-voltage preamplifier
5- Temperature Controller
6- Oscilloscope
7- Spectrum Analyzer
8- Personal Computer
9- Room Temperature Monitor

Spectral Response Calibration

Existing 2 μm Detector Technology

- ❖ InGaAs extended range detectors peak at 2.1 and 2.4 µm,
  depending on the composition.
- ❖ HgCdTe detector peaks at 2.5 µm
- ❖ Both materials ha

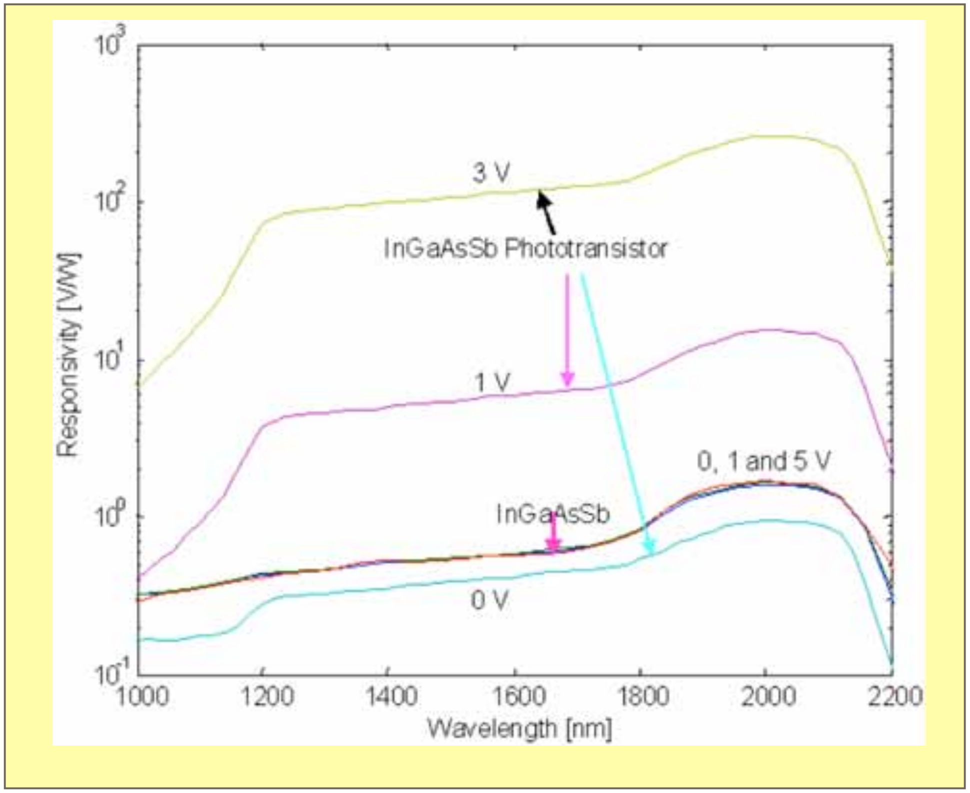


- PbS Reference Detector.
- 40 nm Spectral Resolution.
- 20 °C Temperature.
- 0 V Bias.

Spectral Response Calibration

Existing and Custom-designed LPE-grown InGaAsSb Photodiode and Phototransistor Technology

- PbS Reference Detector.
- 40 nm Spectral Resolution.
- 20 °C Temperature.
- 0 - 5 V Bias.



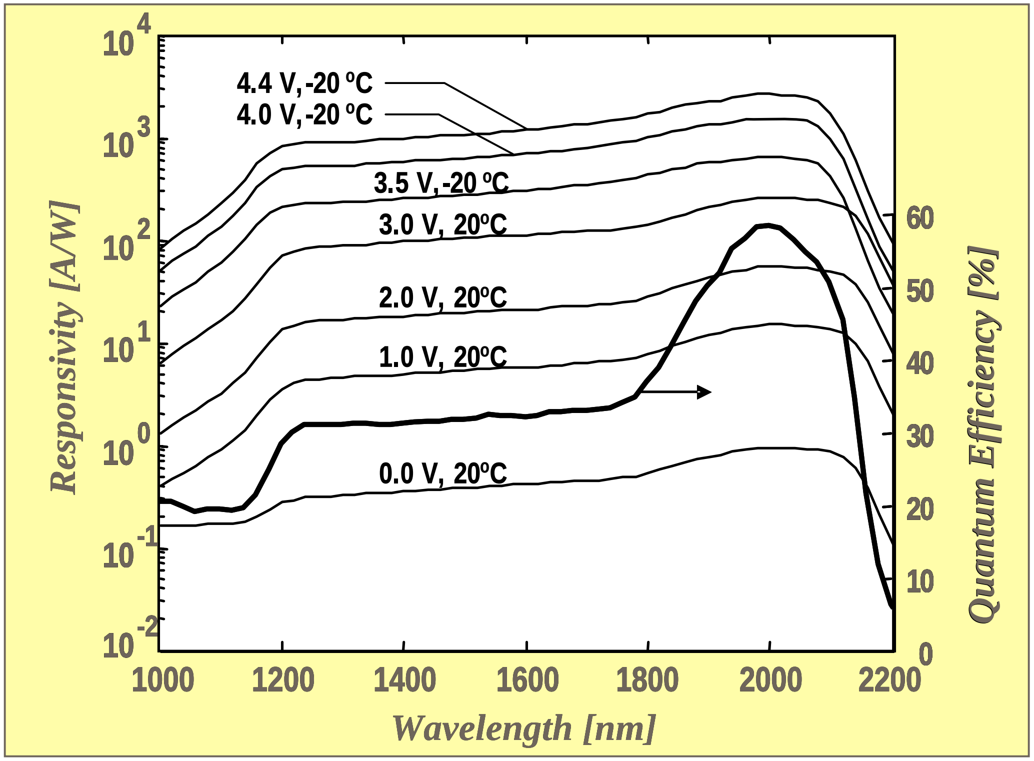
Two-micron Detector Development

Spectral Response Calibration

Custom-designed LPE-grown Detector Technology

❖ InGaAsSb detector (A1-b1) peaks at 2 µm with broad spectral period

- PbS Reference Detector.
- 20 nm Spectral Resolution.
- -20 to 20 °C Temperature.
- Different Bias Voltages.
- Calculated Quantum Efficiency for 0 V at 20 °C



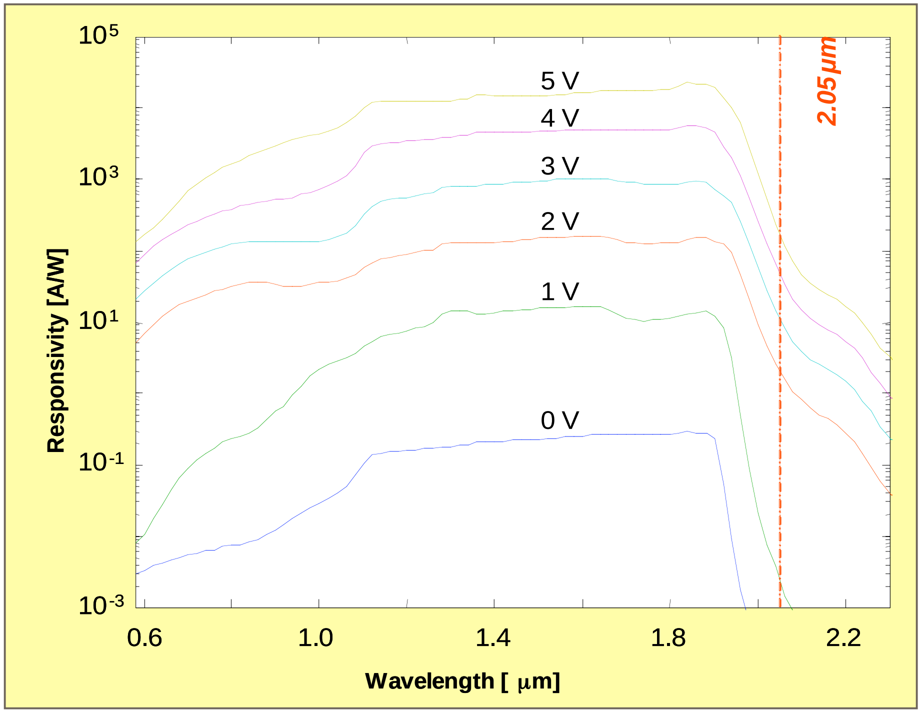
Two-micron Detector Development

Spectral Response Calibration

Custom-designed LPE-grown Detector Technology

❖ InGaAsSb detector (A1-d2) with broad spectral period (0.6- to 2.4-μm)

- Spectral response at 80K
- Increasing the bias voltage regain the 2 μm sensitivity.
- Observed very high responsivity (10000A/W).



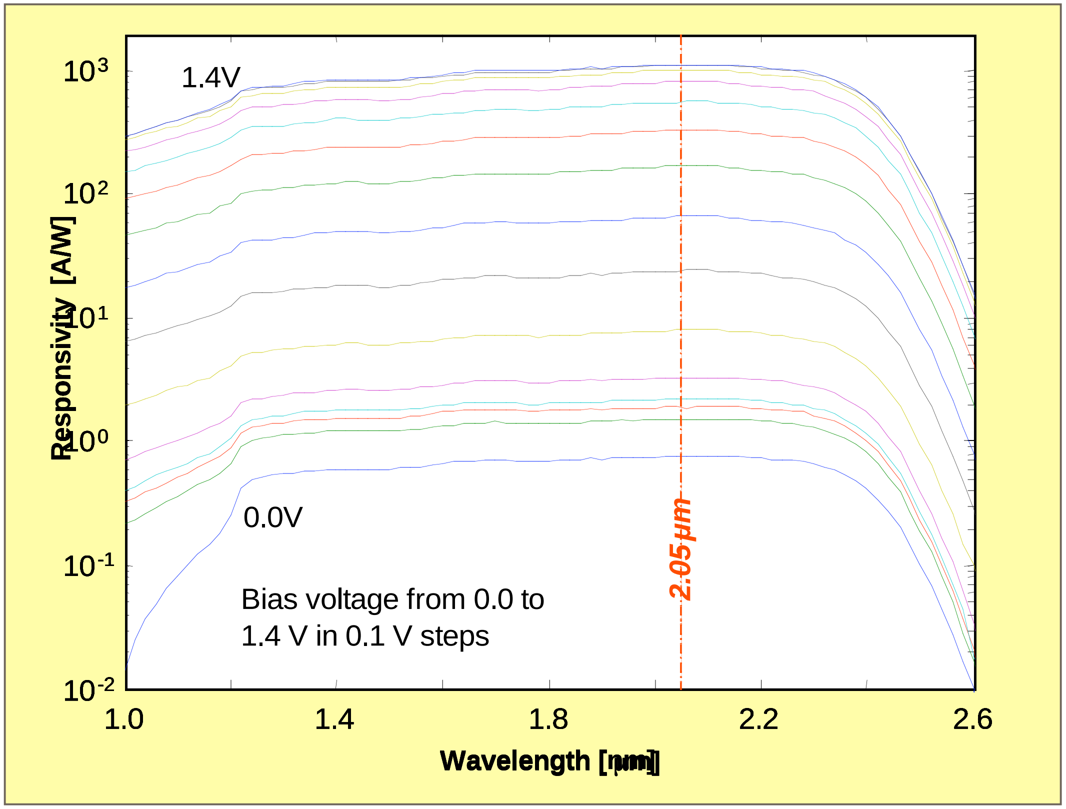
Two-micron Detector Development

Spectral Response Calibration

Custom-designed MBE-grown Detector Technology

- InGaAsSb detector (M1-A2) with broad spectral period

- PbS Reference Detector for 1000 nm to 2600 nm.
- 20 nm Spectral Resolution.
- 20 ºC Temperature.
- 0V – 1.4 V Bias Voltage.
- MBE-grown Phototransistor cut-off wavelength 2.5-micron for M1-A2.



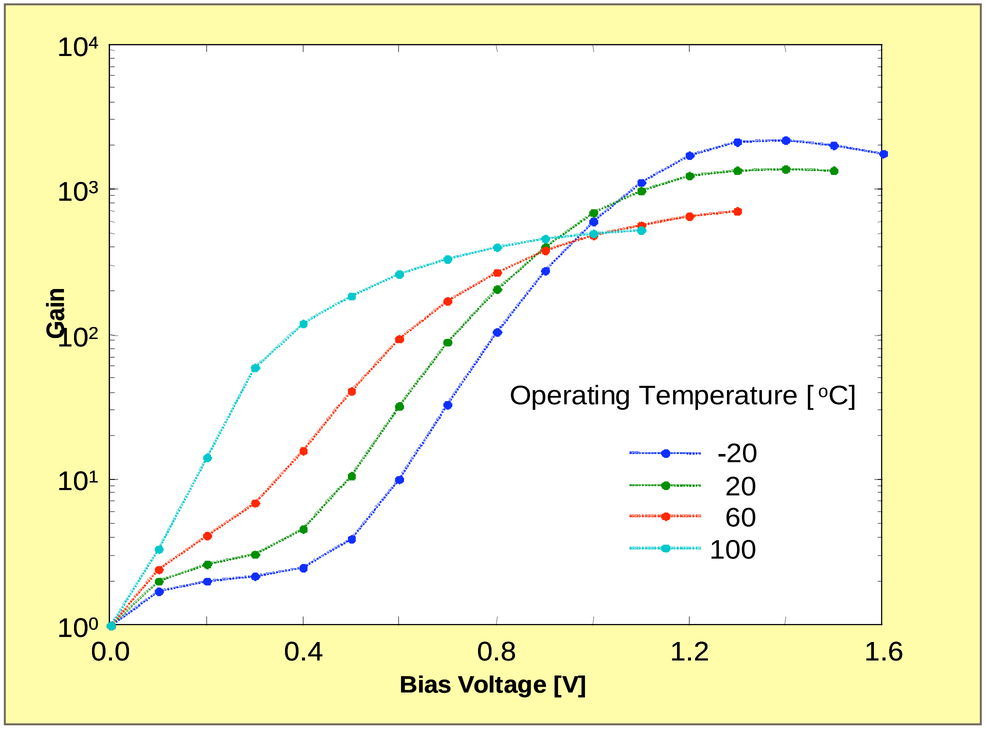
Gain Calculations

Custom-designed MBE-grown 2 μm Detector Technology

❖ Gain variation of an AlGaAsSb/InGaAsSb MBE-grown HPT (M1-A2) with bias voltage and temperatures

$$g = \frac{R_T(\lambda, V, T)}{R_T(\lambda, 0, 20^o C)}$$

- 0V – 1.6V bias voltages with 10mV steps
- -20°C, 20°C, 60°C, and 100°C selected temperatures
- 2.05-μm incident radiation



Detectivity (D*)

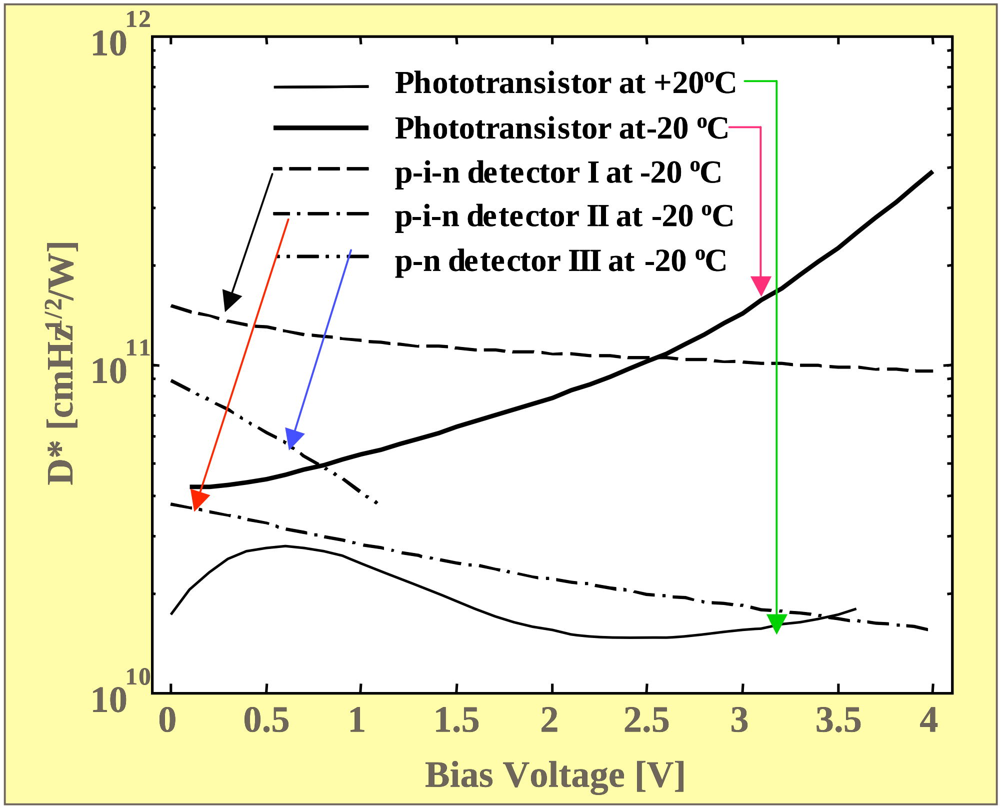
Existing and Custom-Designed LPE-grown 2 μm Detector Technology

Obtained from dark current and spectral response measurements assuming Johnson noise limited performance

$$i_n = \sqrt{\frac{4 \cdot K \cdot T}{R}}$$

$$D^* = \frac{\sqrt{A}}{i_n} \cdot \Re$$

- p-i-n detectors I & II (InGaAs (2.3, 2.6)) and p-n detector III (HgCdTe)
- With suitable bias voltage, InGaAsSb Phototransistor (PT) has the best detectivity, compared to InGaAs and HgCdTe technologies.



Two-micron Detector Development

Detectivity (D*)

Custom-Designed MBE-grown Detector Technology

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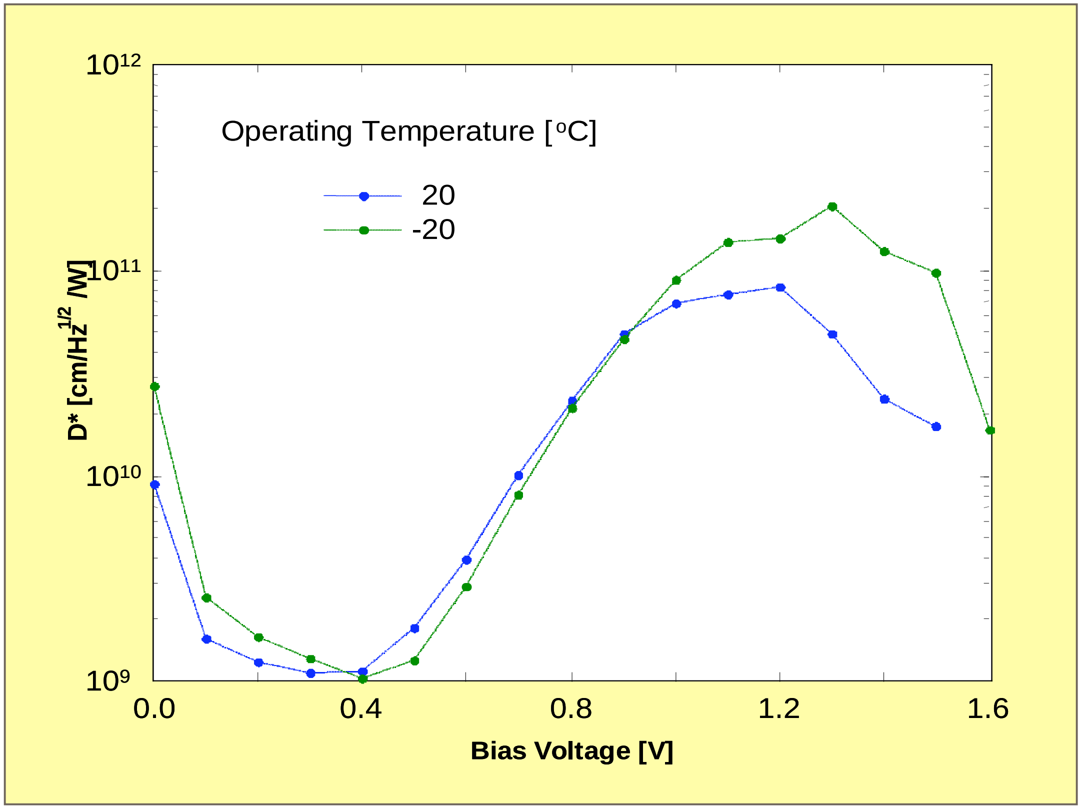
- 0V – 1.6V bias voltages with 10mV steps
- -20°C - 20°C temperature
- 2.05-μm incident radiation



Performance Comparison of Existing Detector to the 2 μm Custom-Designed Detector

Detector	Diameter	Responsivity	Quantum Efficiency	Noise Current Density (I_n)	Noise Equivalent Power (NEP)	Detectivity (D*)
Unit	μm	A/W	%	A/√Hz	W/√Hz	cm.√Hz/W
InGaAs (Off the Shelf)	1000	1.0004	62.1	$7.3\text{x}10^{-13}$	$7.3\text{x}10^{-13}$	$1.2145\text{x}10^{11}$
InGaAs (Off the Shelf)	1000	1.1134	70.4	$3.5\text{x}10^{-12}$	$3.1\text{x}10^{-12}$	$2.8192\text{x}10^{10}$
HgCdTe (Off the Shelf)	1000	0.8761	54.4	$1.9\text{x}10^{-12}$	$2.2\text{x}10^{-12}$	$4.0862\text{x}10^{10}$
InGaAsSb (Off the Shelf)	200	1.018	63.2	$6.2\text{x}10^{-12}$	$6.1\text{x}10^{-12}$	$2.9104\text{x}10^{9}$
InGaSb/GaSb (Custom-designed)	800	0.9374	58.2	$7.8\text{x}10^{-12}$	$8.3\text{x}10^{-12}$	$8.5201\text{x}10^{9}$
InGaSb (Custom-designed)	200	0.5637	35.0	$6.4\text{x}10^{-13}$	$7.6\text{x}10^{-13}$	$2.3418\text{x}10^{10}$
InGaAsSb (Custom-designed)	200 (LPE)	2646 @253K & -4.4V	58.0	$12.2\text{x}10^{-11}$	$4.6\text{x}10^{-14}$	$3.9\text{x}10^{11}$
	300 (MBE)	1128 @253K & -1.3V	~50	$14.28\text{x}10^{-11}$	$12.66\text{x}10^{-14}$	$2.1\text{x}10^{11}$

Two-micron Detector Development

Conclusions

- Developed custom-designed photoransistors at AstroPower and University of Delaware under NASA contracts.

- Characterized them at NASA LaRC to measure the responsivity and dark current. Device performances have been demonstrated in the laboratory to determine responsivity, detectivity and noise equivalent power
  - Results show high responsivity of 1128 A/W corresponding to an internal gain of 2000, high detectivity (D*) of $2.1 \times 10^{11} cmHz^{1/2}/W$ that is lower than the LPE-grown phototransistor of $3.9 \times 10^{11} cmHz^{1/2}/W$ for the same
  wavelength and temperature.

- These phototransistors have great potential for lidar remote sensing applications and this technology will improve the capabilities to measure atmospheric pollutants for future Earth Science measurements.

- This technology has also applications to NASA's Human and Robotic Exploration Program for use in 3-D imaging for planetary mapping and

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